MINUTES
THERMAL EMISSION MEETING #1
DLR, Berlin, Nov 9-11, 2010

Björn J. R. Davidsson
Dep. of Physics and Astronomy, Uppsala University, Sweden

January 12, 2011

Contents

1 Participants

In alphabetic order,

1. Bandfield, Joshua (University of Washington, USA)
2. Bauch, Karin (DLR, Berlin, Germany)
3. Davidsson, Björn (Uppsala University, Sweden)
4. Gutiérrez, Pedro (Instituto de Astrofísica de Andalucía–CSIC, Granada, Spain)
5. Helbert, Jörn (DLR, Berlin, Germany)
6. Mueller, Thomas (Max–Planck–Institut für extraterrestrische Physik, Garching, Germany)
7. Rickman, Hans (Uppsala University, Sweden / PAN Space Research Center, Warsaw, Poland)
8. Wilska, Magdalena (PAN Space Research Center, Warsaw, Poland)

The meeting was hosted by Jörn Helbert, organized and chaired by Björn Davidsson. The meeting consisted of presentations (often interrupted by spontaneous discussions), planned discussions on various topics, a visit to the Planetary Emissivity Laboratory at DLR, and formulation of action items.

2 Presentations

Day 1 and 2 were dominated by presentations given by Bandfield, Rickman, Davidsson, Bauch, Mueller and Helbert. Instead of attempting to summarize the contents of these presentations in these Minutes, we should post the powerpoint files on a website from which they can be downloaded.

3 Discussions

Davidsson had prepared a number of debate topics (see Agenda and "discussions" powerpoint presentation). Here, the topics and the discussions that followed are summarized.

3.1 Solar System diversity versus standard assumptions

Assumptions that work fine for some Solar System bodies may not be suitable for others. For example, in models it is often assumed that visual radiation is absorbed (and near–infrared radiation is emitted) within an infinitely thin surface layer. This may be a very good assumption for rocky materials, but what about ices? A reduction of opacity at VIS/NIR may lead to solid–state greenhouse effects, and it may be necessary to use a modeling approach similar to that used at sub–mm/mm wavelengths (coupled radiative transfer and heat conduction codes). *Is there a danger in applying "standard models" to all Solar System bodies?*

Mueller: A few TNOs have such extremely low IR fluxes (an order of magnitude lower than expected) that the geometric albedo needs to be extremely close to unity. This could perhaps indicate that models, that work fine for the main belt, may not be directly applicable to TNOs?

Davidsson: If some of the solar energy is used for sublimation of e.g. N_2 or CO_2, the geometric albedo could be far below unity, and the IR flux would still be low.

?: Surface frosts have indeed been found in observations of TNOs (N_2, CH_4). Carbon monoxide only found on Pluto so far.

Helbert: Can you maintain sublimation over sufficiently long time periods? Would you not run out of ice? Would be important to investigate how the sublimation process affects surface properties, like porosity and conductivity.

Davidsson: What about Centaurs? Here, N_2 should have been burned off and water is not active.

Mueller: Additional information from occultations. E.g. the Eris occultation shows it is smaller but more massive than Pluto. Haumea has a collisional family.

Rickman: Another example of problematic behavior: Comet Halley had a huge production rate, but the surface was still at 300 K.

3.2 Thermophysical models

One objective of the Thermal Emission Team was to make an inventory of thermophysical models and codes used to interpret thermal emission measurements. It would be important to characterize typical assumptions and simplifications (and when they loose validity), to compare codes with each other, and to cross–check theoretical predictions with laboratory data. *How do we verify thermophysical model performance?*

Helbert: Attempts to investigate the applicability of thermophysical models (developed to study complex sublimation problems) were made during the KOSI experiments. The problem was that the ice and dust mixtures prepared in the laboratory are difficult to characterize, and there are so many parameters to vary.

Bandfield: It is very difficult to produce a realistic test experiment since we do not know the properties of the bodies we try to study.

Helbert: It is not necessary to reproduce a piece of the Moon. Whatever material and topography that is set up in the lab – the model should be able to reproduce the behavior of *that* sample.

Davidsson: Many years ago, experiments were made in Finland where the light scattering from macroscopic irregular bodies with particulate surfaces where measured. Lightcurve inversion and tests of Lumme light scattering theory were made to see if models could recover the known properties of the bodies. I find that kind of tests very interesting.

Mueller: Important to investigate effect of roughness on different size scales. Even if the global irregular shape is known, i.e. from lightcurve inversion or flyby, this never seem to be enough – subfacet roughness always seem necessary when fitting models to measurements.

Bandfield: My experience is that models with flat surfaces, used for subpixel surfaces, generally reproduce measured temperatures rather well.

Mueller: Close to opposition and at short wavelengths the importance of roughness is large. At longer wavelengths (beyond the thermal emission peak) and at larger phase angles the roughness effects are small.

3.3 Resolved targets

The number of small Solar System bodies for which spatially resolved IR spectroscopy has been performed, is steadily increasing. It would be good to set up a database of available observations. These datasets constitute extremely important testbeds for thermophysical models and have, so far, not been used to the full potential. For example, it would be extremely valuable to apply different models to the same datasets and compare results. *IR spectroscopy of resolved targets should be used more systematically to test thermophysical codes.*

Davidsson: The Deep Impact observations of the resolved nucleus of Comet 9P/Tempel 1 has so far only been investigated by two teams, using similar and rather simple models. The interpretation of this modeling is not straightforward and it would be desirable to involve more team and different models in the analysis.

Mueller: It would be interesting to apply the Lagerros model to the target (using the detailed shape model, spin axis solution and material parameters deduced from the resolved observations) apply it to the illumination/observations conditions of previous/future Spitzer and Herschel observations, to see if such disk–integrated data can be reproduced. What is the albedo of Comet 9P/Tempel 1?

Davidsson: The Bond albedo is 0.013.

Mueller: Is an albedo of 1% realistic? Is there any known material that is so dark?

Davidsson [I checked this after the meeting]: Barucci *et al.* (1994, *Icarus* **110**, 287–291) presents a laboratory reflectance spectrum of kerogen (an organic substance that could be a possible comet material analog), which has a $0.5\,\mu$m reflectance of about 0.01, increasing towards 0.04 at $0.9\,\mu$m (remaining there up to $2.5\,\mu$m). So, such extremely low albedos cannot be excluded.

Mueller [additional comment after the first draft of the Minutes]: The Bond albedo of 0.013 corresponds to a geometric albedo of about 3%. This is perfectly reasonable. I don't think that there is a body with 1% geometric albedo.

Davidsson: I am fascinated by the LRO measurements made for the same terrain and illumination conditions, but different emergence angles, showing a systematic change in thermal spectral behavior. This is most likely due to roughness, i.e., one see different parts of the terrain in different viewing geometries. It would be interesting to apply the rough–surface 1D heat conduction model of Gutiérrez and the rough–surface 3D heat conduction model of Davidsson & Rickman to this dataset!

Bandfield: I will investigate if this dataset can be shared with people outside the LRO team at this point in time.

Bandfield: Note, that if we can specify certain observations that would help us solve a particular problem, LRO could perform those observations "on demand".

3.4 Disk–integrated observations

Disk–integrated observations have been made for a large number of minor Solar System bodies with many different instruments and detectors. *How can modeling of disk–integrated targets benefit from lessons made when analyzing disk–resolved targets – and vice versa?*

?: In order to relate observables like the geometric albedo with parameters interesting for the thermophysical modeler (Bond albedo), the phase function has to be well characterized. Normally, the phase function can only be measured in the Sun–body–Earth plane (then assumed symmetric in out–of–plane direction), but it would be valuable to understand the full angular dependence.

Mueller: I believe that the phase function is an important aspect which requires more attention, especially for the high–albedo objects (icy bodies, TNOs, satellites etc). There is a discussion on that subject in Brucker *et al.* (2009). High albedos of low inclination Classical Kuiper Belt Objects. *Icarus* bf 201, 284.

Bandfield: LRO has produced a huge dataset of disk–resolved observations that one in principle could be used to reconstruct the complete phase function. A problem could be that LRO typically has nadir pointing.

?: Lutetia is an exceptionally good target for testing models since both disk–resolved data from Rosetta and disk–integrated data from many IR observatories (including Herschel) are available.

Mueller: The original ISSI proposal mentioned the organisation of a database for disk–integrated thermal data. This would still be very useful.

3.5 Laboratory measurements

Laboratory measurements of various optical properties has been made for a wide range of materials, wavelength ranges, physical conditions et cetera. However, there are still many unsolved issues. The high–temperature spectroscopic behavior of minerals investigated at PEL is an example of exploration in a "new" part of parameter space. What is missing? Have the effects of space weathering on thermal emission been studied? What about the effects of macroscopic topography, roughness and 3D heat conduction on IR spectra? *What are the important problems and questions not yet studied in the laboratory?*

Helbert: It is important to understand exactly what conditions that are "useful" for the Solar System scientist. Many measurements have been performed, i.e., in temperature regimes that are not applicable to our kind of problems.

Davidsson: There is also the problem of not knowing exactly under what conditions a measurement was made. Without proper documentation, one looses track of the conditions under which measurements are valid.

Davidsson: Is there a database or online tool, which allows you to specify a wavelength range, and you get a list of minerals etc what have absorption features in that particular range?

Helbert: Not as far as I know.

Helbert: We have the capability at PEL to measure emissivity out to 200 μm. However, so far we have not seen any explicit interest from people to go that far. It would be good to investigate if there is need for measurements at such long wavelengths.

Davidsson: What about emissivity at sub–mm and mm wavelengths? Who is doing such measurements, and what is available?

Helbert: ISSI could be interested in that kind of survey. I could have a look into this.

Bandfield: There are many ways of performing measurements. In some cases, complex refractive indices are measured and various models are applied to calculate desired properties. However, it would often probably be better to design laboratory experiments where those properties are measured directly.

Davidsson: There has been many measurements of optical properties of minerals where the samples either are in the form of powder, compressed pellets or solid (flat). For me, it would be very interesting to measure the behavior of macroscopic rough terrain, in order to investigate the effects of shadowing, self heating, 3D heat conduction on e.g. the directional emissivity.

Helbert: We have a large vacuum chamber at DLR that is not used. I can investigate if it could be used for that kind of study.

Bandfield: We see changes in spectral properties with emergence angle that so far has not been reproducible in the laboratory. It would be important to investigate phase functions and dependence of thermal emission on incidence and emergence angles.

Helbert: This could be done in the vacuum chamber.

Davidsson: I would like to see measurements of the IR emission spectra for organic material.

3.6 Calibration

A general discussion about calibration.

?: Problem with broadband observations – when the observed spectrum differs too much from that of the calibration target, correction factors get large and the results are unreliable.

Bandfield: Calibration problems are often revealed when data sets for different wavelength–regions (or overlapping regions) from different instruments are combined (systematic offsets).

3.7 Where do we go from here?

There are two major questions:

• Should we attempt to make a second application to ISSI?

• Regardless if we get financed or not – are there specific, concrete problems we want to study as a team or within subgroups of the team?

For the second application see Sec. 4.1. For projects that were discussed see remainder of Sec. 4.

3.8 Miscellaneous

Various questions, comments, and thoughts that were mentioned.

1. Mueller: how is LRO instrument calibration done? Bandfield: instrument staring at calibration target of known temperature. Mueller: important that observed object and calibration target have similar temperatures.

2. Mueller: At very long wavelengths, asteroids emissivity spectra turn flat, but the sub–mm/mm region has a more complex behavior. Laboratory measurements on analog materials in this wavelength region would be helpful.

3. Mueller: It is puzzling that the spectral behavior of most asteroids beyond 50 μm can be reproduced with the same standard set of model parameters. Gutiérrez: one should check if different parameter sets may reproduce the same data – spectral homogeneity may not mean physical homogeneity among bodies.

4. Bauch: presents modeled and measured temperature maps of lunar terrains, that agree very well with each other. Davidsson: it could be worth to check if discrepancies (if any) shows any correlation with the degree of roughness in various location. However, the degree of roughness above the resolution limit may not have anything to do with the degree of roughness on much smaller size scales.

5. Mueller: Asteroid occultations important for constraining sizes, but databases missing (at least using some standardized format). Perhaps something for ISSI?

6. Davidsson: Since stars are too faint and planets are too bright, spaceborne IR instruments often use asteroids as calibration targets. Models are ran for a certain standard parameter set, thereby predicting the flux at a certain wavelength, which then is used to calibrate the instrument. But how were those parameter sets obtained in the first place? At some point a well–calibrated instrument must have been used to observe the asteroids? Mueller: stellar sources etc.

7. Davidsson: The geometric albedo of TNOs can be derived from observations, but evaluation of the Bond albedo (needed for the energy budget in thermophysical models) require that the phase function can be measured. This requires observations at a large range of phase angles, which is not possible for TNOs. Perhaps this contributes to the difficulties of analyzing IR observations of TNOs.

8. Mueller: It would be helpful to set up a publicly available reference dataset, that could be used for model code verification, performance tests etc.

9. Davidsson: Regarding laboratory measurements of parameters of interest in planetology – these can sometimes be found in completely different scientific communities (e.g., heat conductivity measurements for silicate mixtures versus temperature and porosity made in laboratories for superconducting magnets, who need to characterize their isolation materials).

10. Helbert: In our emissivity measurements of minerals at various temperature we see a sometimes strong dependence of the location and profile of absorption features on temperature.

11. Bandfield: What is the physical reason for this dependence?

12. Helbert: The sizes and shapes of crystals change with temperature and affects reflectance and emission properties.

13. Davidsson: Meteoritic material with petrologic grade 3 often has large variations in Mg/Fe ratios on physically small size scales, that gradually disappear with heating (increasing petrologic grade) due to atomic mobility. Could corresponding changes in spectral properties be investigated at PEL?

14. Helbert: Yes.

15. Mueller: Since spacecraft cannot observe with the Sun in the back, there is virtually no opposition data (except in a few cases where small phase angles are achieved during flyby). Furthermore, thermal phase curves are virtually non–existing.
16. Davidsson: I think Cassini has observed thermal phase curves as well as the thermal opposition effect in Saturn ring particles.
17. Bandfield: LRO has performed zero phase observations of the Moon.
18. Bauch: Conductivity is strongly dependent on temperature, at least on the Moon. Can such a dependence be seen in minor bodies, i.e. when transiting from the main belt to the TNO population?
19. ?: Concerning roughness, it is very difficult to say whether there is a systematic difference between main belt asteroids and TNOs, because key data (close to opposition) is not available.
20. Davidsson: Temperature maps of both Tempel 1 and Steins look virtually isothermal, there is very little variation with rotational phase. However, Saturnian moons have a clear day–night variation. Why are the behavior so fundamentally different? Is it difference in composition and roughness, or is it just that surface–roughness only is "visible" in the high–temperature regime?
21. Rickman: It would be good to run the Gutiérrez model for Saturnian moon conditions, to see if roughness effects on thermal IR spectra is strongly dependent on temperature.
22. ?: It would be very valuable to have ground truth on TNO sizes (New Horizons?). It would help us to understand if solid–state greenhouse effects are of importance for these bodies.

4 Action Items

A number of projects were defined, were various team members work together to investigate specific issues. All team members are welcome to participate in one or several of these projects, and everybody are also welcome to propose new topics. These projects may form the core of a second proposal to ISSI, and provide some much–needed concretization of proposed work. First the discussion concerning the second proposal itself is summarized, then the different projects are described (order not reflecting degree of importance).

4.1 Second ISSI application

Rickman summarized previous events – the Letter of Intent received encouraging comments from ISSI, but the Application was not approved (a short email from ISSI stated the proposal was "good" but was not among the 48% of proposals that got funded, and that we perhaps could submit "a better proposal next year"). The team discussed two possible reasons for the failure; a) ISSI is downscaling its engagement in planetology; b) the proposal itself had important shortcomings.

Helbert checked the list of approved proposals and found that only two were related to planetology, while the overwhelming majority concerned astrophysics. Hence, there may indeed have been a shift in ISSI priorities that was unfavorable to us. However, it was also agreed that the original application was too vague and unfocused. A new application should contain *more concrete goals*, focus on the *derivation of physical properties of Solar System bodies through thermophysical modeling*, and it would be good to demonstrate that *collaboration between team members already had been initiated*. Also, the proposal should focus on *measured data we already have access to within the team*, and not dwell on data we may (or may not) have access to in the future.

Rickman reminded us that many original team members were not present, that we should await their input. Gutiérrez mentioned that others may want to join the team. One possibility is to have a "core team" and invite specific people to specific meetings when their input is needed.

• AI, Rickman: Investigate how many of the current team members that are willing to participate in a new proposal. Collect opinions and suggestions from entire team.

• AI, Rickman: Check with ISSI how large teams (or perhaps, how many "man hours") they finance.

4.2 Models versus macroscopic terrains in the laboratory

In order to analyze IR spectra from atmosphereless Solar System bodies, advanced thermophysical models are used which often consider macroscopic roughness with shadowing, self heating etc. However, such models have never been tested against laboratory measurements of emission from macroscopic terrains, simply because such measurements are not available.

• AI, Helbert: Investigate whether the large vacuum chamber at DLR could be used to perform thermal emission measurements on macroscopically rough terrains.

4.3 Database over disk–resolved observations

The number of spatially resolved minor Solar System bodies observed by IR spectrometers is growing rapidly. It would be good to set up a database over available observations.

• AI, Davidsson: Set up a database over disk–resolved IR spectroscopic observations.

Mueller advises to organize the database object–by–object rather than instrument–by–instrument.

4.4 The Deep Impact observations of Comet 9P/Tempel 1

The Deep Impact 1–5 μm spectra have been investigated using thermophysical models using both flat and rough terrains, in both cases assuming 1D heat conduction. Due to difficulties in interpreting the results further modeling efforts is desirable.

• AI, Mueller: Use the Lagerros & Mueller thermophysical model to produce synthetic spectra (known body shape, spin axis orientation, applying various parameter sets to describe surface properties) and investigate under which conditions available disk–integrated observations by Spitzer (Herschel?) can be reproduced.

4.5 Roughness on the Moon

LRO has performed observations of the same lunar terrain at constant incidence angle, but for a variety of emergence angles e. The thermal infrared spectra changes systematically with e, in a way that cannot easily be reproduced with models allowing for first–order roughness effects (stochastic slope variations included, but projected shadows neglected).

• AI, Bandfield: Investigate whether data can be shared outside the LRO team at this stage.

• AI, Davidsson, Rickman, Gutiérrez (others?): If data available, apply different thermophysical models to data to test their performance and suitability.

4.6 Challenges with TNO data analysis

A few TNOs are difficult to model with standard tools. Near the Planck peak they emit a flux that differ an order of magnitude with respect to predictions made by standard models evaluated for standard parameter set. These objects differ systematically from main belt asteroids and NEAs by their large heliocentric distances, possibly high albedos, composition, and physical behavior which may include sublimation of volatiles like CO and N_2. It was decided to evaluate the performance of currently applied methods by producing synthetic observations and compare model solutions with known "ground truth".

• AI, Gutiérrez: Run his thermophysical model for high–albedo, sublimating, irregular target at large heliocentric distance, use the thus obtained surface temperatures to produce synthetic near– to far–infrared spectra (e.g., versus rotational phase for specific illumination/observational geometry). Perhaps different model runs where sublimation is switched on/off. Consider both Saturnian moon and TNO cases.

• AI, Mueller (Emery? others?): Analyze synthetic spectra, as would have been done if measured by Spitzer or Herschel. Make predictions on target size, shape, albedo, reflectance/emissivity spectra, surface temperatures *et cetera*. Compare with actual model bodies, analyze similarities and differences.

Helbert pointed out that these should be "blind tests" since previous experience has shown that knowledge on what properties the target is *believed* (or is known) to have, sometimes affect the way data analysis is made.